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METHOD FOR ESTIMATING THE DEGRADATION OF THE TRAPPING CAPACITY OF A NOx-TRAP TYPE CATALYTIC CONVERTER

PRIORITY CLAIM

[1] This application claims priority from Italian patent application No. BO2003A filed on March 13, 2003, which is incorporated herein by reference.

TECHNICAL FILED

[2] The present invention relates to a method for estimating the degradation of the trapping capacity of a NOx-Trap type catalytic converter.

[3] The present invention is advantageously applied to an internal combustion automotive engine supplied with fuel by direct injection of petrol into the cylinders and having combustion with a lean mixture and stratified charge, to which the following description will make explicit reference without thereby restricting the general scope.

BACKGROUND

[4] A direct injection petrol engine comprises an exhaust manifold, which communicates with the cylinders by means of the respective exhaust valves and terminates in an exhaust pipe equipped with a precatalytic converter capable of promoting the conversion of the NO groups produced during combustion into NO_2 and a subsequent NOx-Trap catalytic converter capable of trapping the NO_x groups and so preventing their release into the atmosphere. The NOx-Trap catalytic converter traps within itself both the NO_x groups produced during combustion and the sulfur (in the form of SO_x) that is contained in the fuel and is released during combustion; moreover, the NOx-Trap catalytic converter itself has a limited trapping capacity (generally of between 3 and 5 grams) and when said trapping capacity is exhausted, the NOx-Trap catalytic converter must be cleaned by a regeneration process.

[5] The total mass of NO_x groups produced during combustion is much greater than the mass of sulfur released during combustion; moreover the regeneration process to remove NO_x groups (a few seconds of rich combustion) is much shorter than the regeneration process to remove sulfur (of the order of 30-60 seconds of rich

combustion combined with an internal temperature in the catalytic converter that is very much higher than the normal operating temperature). For the reasons stated above, the regeneration process to remove NO_x groups is normally carried out every 45-75 seconds of engine operation, whereas the regeneration process to remove sulfur is normally carried out every 6-12 hours of engine operation.

[6] The regeneration processes are scheduled by a central control unit using a storage model for the NOx-Trap catalytic converter, said model being based on a knowledge of the estimated trapping capacity of the NOx-Trap catalytic converter, and using a model of the production of NO_x and SO_x group by the engine. Each time NO_x regeneration of the NOx-Trap catalytic converter is performed, the central control unit checks, using the signal from a lambda probe and/or a NO_x probe provided downstream from the NOx-Trap catalytic converter, whether the actual duration of the NO_x regeneration process is less than a predetermined value on the basis of the current model; if this is the case, i.e. if the actual duration of the NO_x regeneration process is less than the predetermined value, it is clear that the NOx-Trap catalytic converter has trapped a smaller quantity of NO_x than predicted and the central control unit accordingly assumes that said phenomenon is due to degradation of the NOx-Trap catalytic converter and reduces the estimate of the trapping capacity of the NOx-Trap catalytic converter used in the storage model for the NOx-Trap catalytic converter.

[7] However, experimental trials have revealed that, when the above-described method is used, there is a tendency to underestimate the actual trapping capacity of the NOx-Trap catalytic converter, with a consequent increase in fuel consumption (and thus in the level of atmospheric emissions), due to the fact that underestimating the actual trapping capacity of the NOx-Trap catalytic converter results in NO_x regeneration processes being carried out more frequently.

SUMMARY

[8] The object of the present invention is to provide a method for estimating the degradation of the trapping capacity of a NOx-Trap type catalytic converter, which method does not have the above-described disadvantages and, in particular, is simple and economical to implement.

[9] The present invention provides a method for estimating the degradation of the trapping capacity of a NOx-Trap type catalytic converter as defined in Claim 1 and, preferably, in any one of the subsequent claims directly or indirectly subordinate to Claim 1.

BRIEF DESCRIPTION OF THE DRAWING

[10] The present invention will now be described with reference to the attached drawing, which illustrates a non-limiting embodiment; in particular, the attached figure is a schematic view of an internal combustion engine, which is controlled by a control unit that implements the estimation method provided by the present invention.

Detailed Description

[11] In the attached **FIG. 1** denotes the overall internal combustion engine equipped with four cylinders ***2*** (only one of which is shown in **FIG. 1**), each of which is connected to an intake manifold ***3*** via at least one respective intake valve ***4*** and to an exhaust manifold ***5*** via at least one respective exhaust valve ***6***. The intake manifold ***3*** receives fresh air (*i.e.*, air originating from the outside environment) via a throttle valve ***7*** that is adjustable between a closed position and a maximally open position. Petrol is injected directly into each cylinder ***2*** by a respective injector ***8***.

[12] From the exhaust manifold ***5*** there leaves an exhaust pipe ***9***, which comprises a catalytic preconverter ***10*** and a subsequent NOx-Trap catalytic converter ***11***; inside the exhaust pipe 9 there is installed a UEGO probe ***12***, which is arranged upstream from the catalytic preconverter ***10*** and is capable of detecting the quantity of oxygen present in the exhaust gases entering the catalytic preconverter ***10***, a temperature sensor ***13***, which is arranged between the catalytic preconverter ***10*** and NOx-Trap catalytic converter ***11*** and is capable of detecting the temperature of the gases entering the NOx-Trap catalytic converter ***11***, and a multisensor ***14***, which is arranged downstream from the NOx-Trap catalytic converter ***11*** and is capable of detecting either the presence of NO_x groups (nitrogenous group sensor) or the quantity of oxygen present relative to stoichiometric conditions (lambda probe) in the exhaust gases leaving the NOx-Trap catalytic converter ***11*** (*i.e.,* in the exhaust gases released from the exhaust pipe ***9*** into the atmosphere).

[13] The engine ***1*** furthermore comprises a control unit ***15*** which, inter alia, on each cycle controls the throttle valve ***7*** and the injector ***8*** to fill the cylinder ***2*** with a quantity of combustion agent (fresh air) and fuel in a specific ratio as a function of the operating conditions of the engine **1** and as a function of the commands received from the driver; in particular, the control unit ***15*** is capable of causing the engine ***1*** to operate by combustion with a lean mixture and stratified charge. In order to allow the control unit ***15*** to capture the data required for correct operation thereof, the control unit ***15*** is connected to the UEGO probe ***12***, the temperature sensor ***13*** and the multisensor ***14***.

[14] In service, the NOx-Trap catalytic converter ***11*** stores either the NO_x groups produced during combustion or the sulfur (in the form of SO_x) contained in the fuel and released during combustion, in order to prevent said constituents from being released directly into the atmosphere. The NOx-Trap catalytic converter ***11*** has a limited trapping capacity C for NO_x groups and sulfur (normally amounting to ***4*** grams) and when said trapping capacity C is exhausted the NOx-Trap catalytic converter ***11*** must be cleaned by means of a regeneration process. The total mass of NO_x groups produced during combustion is much greater than the mass of sulfur released during combustion, and moreover the regeneration process to remove NO_x groups (a few seconds of rich combustion of the engine) is much shorter than the regeneration process to remove sulfur (indicatively 30-60 seconds of rich combustion combined with an internal temperature in the NOx-Trap catalytic converter ***11*** that is very much higher than the normal operating temperature). For the reasons stated above, the regeneration process to remove NO_x groups is normally carried out every 45-75 seconds of operation of the engine ***1***, whereas the regeneration process to remove sulfur (also known as the desulfation process) is normally carried out every 6-12 hours of operation of the engine ***1***.

[15] The regeneration processes are scheduled by the central control unit ***15*** using a storage model for the NOx-Trap catalytic converter 11, said model being stored in a memory ***16*** and based on a knowledge of the estimated trapping capacity C of the NOx-Trap catalytic converter ***11***, and using a model of the production of NO_x and SO_x groups by the engine ***1***, said model being stored in the memory ***16***. In particular, the quantity of NO_x produced by the engine ***1*** is obtained in known

manner by the control unit ***15*** using maps that state the specific quantity (*i.e.,* the quantity per unit of fuel injected into the cylinders ***2***) of NO_x and SO_x groups produced by the engine ***1*** as a function of engine status (typically as a function of engine speed and as a function of delivered torque). As is known, the above-mentioned models are determined by means of a theoretical analysis of the systems and by means of a series of laboratory tests carried out on the engine ***1*** equipped with a series of auxiliary measurement sensors, which are capable of providing an instantaneous and accurate measurement of all the parameters involved in the operation of the engine ***1*** itself.

[16] During normal operation of the engine ***1*** and using the storage model for the NOx-Trap catalytic converter ***11***, the control unit ***15*** estimates the quantity of NO_x groups stored in the NOx-Trap catalytic converter ***11***; when said quantity of stored NO_x groups exceeds a predetermined threshold, the control unit ***15*** triggers performance of the NO_x regeneration process. The NO_x regeneration process is of a predetermined duration (stored in the memory ***16***) such that the NO_x regeneration process is performed only for the time required to remove the NO_x groups stored in the NOx-Trap catalytic converter ***11***.

[17] During the NO_x regeneration process of the NOx-Trap catalytic converter ***11***, the control unit ***15*** monitors the signal from the multisensor ***14***; in particular, if no transition in the signal from the multisensor ***14*** from lean to rich is detected during the NO_x regeneration process, then it is assumed that the actual duration of the NO_x regeneration process matches the predetermined duration and that thus the storage capacity C of the NOx-Trap catalytic converter ***11*** is unchanged whereas, if a transition in the signal from the multisensor ***14*** from lean to rich is detected during the NO_x regeneration process, then the actual duration of the NO_x regeneration process was less than the predetermined duration and thus the NO_x storage capacity C has clearly diminished. The signal from the multisensor ***14*** is significant because, while the reduction process of the NO_x groups stored in the NOx-Trap catalytic converter ***11*** is under way, there is an excess of oxygen (relative to the stoichiometric value) in the exhaust gases downstream from the NOx-Trap catalytic converter ***11***, said excess arising from the reduction of the NO_x groups, whereas once the reduction process of the NO_x groups stored in the NOx-Trap catalytic

converter ***11*** is complete, there is a deficit of oxygen (relative to the stoichiometric value) in the exhaust gases downstream from the NOx-Trap catalytic converter ***11*** because a rich mixture is supplied to the cylinders ***2*** during the regeneration process. It is clear from the above description that the signal from the multisensor ***14*** can also be used for estimating the actual duration of a NO_x regeneration process, because, if no transition in the signal from the multisensor ***14*** from lean to rich is detected during the NO_x regeneration process, then it is assumed that the actual value of the duration of the NO_x regeneration process matches the predicted value whereas, if a transition in the signal from the multisensor ***14*** from lean to rich is detected during the NO_x regeneration process, then the actual value of the duration of the NO_x regeneration process is less than the calculated value and is equal to the period of time that has elapsed between the moment at which the regeneration process was initiated and the moment at which the transition in the signal from the multisensor ***14*** occurred.

[18] If, during the NO_x regeneration process of the NOx-Trap catalytic converter ***11***, the control unit ***15*** detects the above-described anomalous transition in the signal from the multisensor ***14***, then the control unit ***15*** attempts to determine the cause that led to the degradation of the trapping capacity C of the NOx-Trap catalytic converter ***11*** and thus attempts, if possible, to remedy such degradation. In particular, when the control unit ***15*** detects the anomalous transition in the signal from the multisensor ***14***, then the control unit 15 increases the operating temperature (indicatively by a step of 20-40°C) of the NOx-Trap catalytic converter ***11*** by acting in known manner on the control of the throttle valve ***7*** and the injector ***8*** and awaits performance of the subsequent NO_x regeneration process; if, during the subsequent NO_x regeneration process, the control unit ***15*** again detects the anomalous transition in the signal from the multisensor ***14***, then the control unit ***15*** further increases the operating temperature (indicatively by a step of 20-40°C) of the NOx-Trap catalytic converter ***11*** and awaits performance of the subsequent NO_x regeneration process. Said process of increasing the operating temperature of the NOx-Trap catalytic converter ***11*** is continued in cycles not until the operating temperature of the NOx-Trap catalytic converter ***11*** reaches a predetermined limiting value, but instead until the control unit ***15*** ceases to detect the anomalous transition

in the signal from the multisensor ***14***; in this latter case, *i.e.,* if the increase in the operating temperature of the NOx-Trap catalytic converter ***11*** has led to the disappearance of the anomalous transition in the signal from the multisensor ***14***, then the control unit ***15*** increases the minimum value of the operating temperature of the NOx-Trap catalytic converter 11 stored in the memory ***16*** by a predetermined quantity because the reduction in the trapping capacity C of the NOx-Trap catalytic converter ***11*** is essentially due to thermal degradation and can be at least partly offset by increasing the operating temperature of the NOx-Trap catalytic converter ***11***. Obviously, the control unit ***15*** does not increase the minimum value of the operating temperature of the NOx-Trap catalytic converter ***11*** beyond a predetermined threshold value in order to maintain an acceptably wide operating temperature range for the NOx-Trap catalytic converter ***11***.

[19] If, on the other hand, the increase in the operating temperature of the NOx-Trap catalytic converter ***11*** did not lead to the disappearance of the anomalous transition in the signal from the multisensor ***14***, then the control unit ***15*** performs an unscheduled desulfation process with a temperature value for the NOx-Trap catalytic converter ***11*** and an average value for ratio equal to the corresponding values used during the preceding desulfation processes. On completion of the unscheduled desulfation process, the control unit ***15*** awaits performance of the subsequent NO_x regeneration process.

[20] If, during the subsequent NO_x regeneration process, the anomalous transition in the signal from the multisensor ***14*** no longer occurs, then the control unit ***15*** increments the temperature value of the NOx-Trap catalytic converter ***11*** and decrements the average value for ratio used during future desulfation processes because the reduction in the trapping capacity C of the NOx-Trap catalytic converter ***11*** is essentially due to the formation of particularly tenacious sulfur crystals. Obviously, the control unit ***15*** does not increase the temperature value for the NOx-Trap catalytic converter ***11*** nor does it decrement the average value for ratio used during desulfation processes beyond the respective predetermined thresholds.

[21] If, on the other hand, the anomalous transition in the signal from the multisensor ***14*** still occurs in the subsequent NO_x regeneration process, then the

control unit ***15*** assumes that this phenomenon is due to irreversible degradation of the NOx-Trap catalytic converter ***11*** and thus reduces the estimated trapping capacity C of the NOx-Trap catalytic converter ***11*** used in the storage model for the NOx-Trap catalytic converter ***11*** by a predetermined amount.

[22] According to another embodiment, the predicted duration of the NO_x regeneration process of the NOx-Trap catalytic converter ***11*** is not assumed to be equal to a predetermined value stored in the memory ***16***, but is calculated before performing the NO_x regeneration process by using the storage model for the NOx-Trap catalytic converter ***11*** and using the model of the production of NO_x and SO_x group by the engine ***1*** in such a manner that the NO_x regeneration process only lasts for the time strictly necessary to remove the NO_x groups trapped in the NOx-Trap catalytic converter ***11***.

[23] From the above explanation, it is clear the control unit ***15***, before reducing the estimated trapping capacity C of the NOx-Trap catalytic converter ***11*** used in the storage model for the NOx-Trap catalytic converter ***11***, attempts to identify the cause of the degradation of the trapping capacity C of the NOx-Trap catalytic converter ***11*** and attempts, if possible, to remedy such degradation; by using this method, it is possible to avoid underestimating the actual trapping capacity C of the NOx-Trap catalytic converter ***11*** and thus to avoid increasing the frequency of NO_x regeneration processes beyond what is strictly necessary.